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**UNCLASSIFIED INFORMATION ON SOVIET
BLOC INTERNATIONAL GEOPHYSICAL COOPERATION
- 1960**

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INFORMATION ON SOVIET BLOC INTERNATIONAL GEOPHYSICAL COOPERATION - 1960

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INTERNATIONAL GEOPHYSICAL COOPERATION PROGRAM —

SOVIET-BLOC ACTIVITIES

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I. UPPER ATMOSPHERE

The Sources of Bay-Shaped Disturbances

The problem of the sources of magnetic disturbances has still not been finally resolved. One of the most well-founded hypotheses is that of the dynamo theory. However, there are also other hypotheses that afford different explanations of the development of electrical currents in the ionosphere: the theory of discharge currents, the theory of the direct action of currents of corpuscles on the Earth's magnetic field, and Martyn's theory — but not one of them provides an exhaustive explanation of the full range of phenomena.

The source material used for the present paper were photocopies of magnetograms of a number of field magnetic variation stations simultaneously operating in the northern part of Western Siberia, near the zone of auroras in 1953, 1954, and 1957. In addition, some use was made of data provided by ionospheric stations at Tikhsi Bay and on Dikson Island.

The organization and implementation of the magnetic observations program were accomplished by the Scientific Research Institute of Arctic Geology (by B. A. Aleksandrov, S. M. Kryukov, D. V. Levin and I. M. Pudovkin). The location of the stations is shown in Figure 1.

Well-expressed bay-shaped disturbances on calm days were selected for analysis; they were traced at a majority of the stations; their duration was between $\frac{1}{2}$ and 3 hours.

A summarization of the analysis of the individual bay-shaped disturbances make it possible to draw the following conclusions:

1. The sources of bay-shaped magnetic disturbances evidently are clouds of high ionization, moving with a velocity of about 120 m/sec. The derived relationship between the vector of the disturbed field and wind direction in the ionosphere and the normal magnetic field of the Earth indicates that the mechanism of excitation of the electrical currents in the ionosphere is evidently the dynamo-effect.

2. The electrical currents responsible for bay-shaped disturbances flow in the ionosphere in the form of broad belts (about 400 km wide on the basis of magnetic data and about 600 km wide on the basis of ionospheric data). The altitude of these currents is 100-150 km, that is, it corresponds to the altitude of the E-layer. The mean density of the current is $8 \cdot 10^{-9}$ a/cm², from which one may conclude that the density of electrons in the zone of the auroras at the time of bay-shaped disturbances increases to $10^5 - 10^6$ electrons/cm³; this is confirmed by the results of observations of the intensity of auroras.

(*Sources of Bay-Shaped Disturbances*, by M. I. Pudovkin, Izvestiya Akademii Nauk SSSR, Seriya Geofizicheskaya, No. 3, 1960, pp. 484-489)

On the Spectra of Auroras

Measurements of the relative intensities of 2PG N₂ in auroras at Saskatoon (Lat — 60° 5') by means of a Shepherd and Hunten photoelectric spectrometer have shown that the vibrational temperature does not exceed 1,000° K. For the auroral zone (Lat — 64°) Omholt's measurements of the relative intensities of 2 PG N₂, as well as Vegard's measurements, have shown a vibrational temperature of about 4,000° K.

This article makes an attempt at determination of latitudinal variations in the relative intensities of the vibrational bands 2PG N₂ in auroras.

Spectra of auroras in the ultraviolet field were recorded at stations of the Institute of Physics of the Atmosphere at Loparskaya, Roshchino and Zvenigorod by standard SP-49 spectrographs.

The correction of the measured intensities for spectral sensitivity of the film, absorption in the atmosphere, etc., was accomplished in two ways. The first method was proposed by Seaton (Excitation Processes in the Aurora and Airglow, Journal of Atmospheric and Terrestrial Physics, 4, No. 6, 1954). The second method involves the direct calculation of the correction factor for spectral sensitivity, Rayleigh scattering and absorption by ozone. The spectral sensitivity determined at Zvenigorod was used for all stations. The coefficients for Rayleigh scattering and absorption by ozone (with correction for latitude) were taken from papers by Petrie and Prokof'yeva respectively (Journal of Geophysical Research, 57, No. 1, 1952 and the book "Atmospheric Ozone", Publishing House of the Academy of Sciences of the USSR, 1955).

The author proceeds with his approach for the approximate determination of vibrational temperature. For a typical high-latitude aurora at Lopanskaya T_{vib} 4,000° K, which agrees with Omholt's results. For low-latitude auroras at Roshchino and Zvenigorod and for Type A auroras at Loparskaya T_{vib} 2,000° K.

The number of processed spectrograms is still small; it is therefore only possible to draw preliminary conclusions. From an examination of Table 2 it may be concluded that the populations of the upper vibrational levels of N₂ in a typical high-latitude aurora are greater than the populations for low-latitude auroras. These latter agree with the values $g(v')$ for a high-level red aurora of type A with strong atomic lines.

The value T_{vib} for typical high-latitude auroras is greater than T_{vib} for low-latitude auroras. Evidently we may draw the conclusion that in low greenish-white forms, characteristic of auroras in the high latitudes, the rigidity of excitation of 2PG N₂ is greater than in red (type A) high-latitude and low-latitude auroras.

("On the Spectra of Auroras", by F. K. Shuyskaya, Izvestiya Akademii Nauk SSSR, Seriya Geofizicheskaya, No. 3, 1960, pp. 510-512)

Refinement in the Concept of the Influence of the Underlying Surface on Scattered Light in the Atmosphere

In the solution of the problem of light scattering in the atmosphere, with due regard for the reflection of light from the underlying surface, it is usually assumed that the brightness of the reflected radiation does not depend on direction (Lambert's Law); for description of reflective properties the albedo value is used, that is, the ratio of the current of surface-reflected radiation to the current falling on its surface.

However, observational data show that natural surfaces do not, generally speaking, reflect radiation in accordance with Lambert's Law. Their reflective properties are characterized by the coefficient of brightness $R(r, r')$ which is determined as the ratio of the brightness of the surface in a given direction to the exposure of this surface, and therefore generally depends on the directions of the falling (r') and reflected (r) rays.

This article deals with the step-by-step mathematical computations involved in determining the value characterizing light scattered in the atmosphere.

(*On the influence of 'Nonorthotropy' of the Underlying Surface on Scattered Light in the Atmosphere", by M. S. Malkevich, Izvestiya Akademii Nauk SSSR, Seriya Geofizicheskaya, No. 3, 1960, pp. 440-448)

Interferometric Temperature Measurements of the Upper Atmosphere

A comparison of the temperatures determined interferometrically by different authors at different latitudes indicates that at the level of luminescence of the line $\lambda 5577\text{\AA}$ in the night sky the temperature of the upper atmosphere at Loparskaya is higher than at lower latitudes. The difference in temperature is rather considerable and appreciably exceeds errors in measurement. An analogous increase in temperature at an altitude close to the level of luminescence of $\lambda 5577\text{\AA}$ was discovered by measurements of the rotational temperature of the OH band.

The value for the temperature, measured at Loparskaya from the width of $\lambda 6300\text{\AA}$, is also higher in the night sky than the value cited by Dufay. However, Dufay's measurements give too low temperatures which do not agree with the most probable altitude of luminescence of $\lambda 6300\text{\AA}$. The temperature measured from the twilight photograph of $\lambda 6300\text{\AA}$ at Loparskaya is somewhat higher than the temperature derived by Wark, but the difference lies in the limits of observational error.

Measurements of the width of $\lambda 6300\text{\AA}$ relating to the night sky, made at Loparskaya, give a mean value of 1200°K for temperature. This corresponds to a height of a homogeneous atmosphere ≈ 90 km, if we assume the mean molecular weight to be 15. On the basis of data on the braking of artificial earth

satellites, the height of the homogeneous atmosphere at a height of 250 km is 60 km for the middle latitudes and increases toward the higher latitudes. The value H , determined interferometrically, is in agreement with this conclusion. Thus, a comparison of the temperatures measured from the lines 5577 and 6300 \AA at different latitudes indicates that there evidently occurs a heating of the upper atmosphere in the high latitudes.

The increase of temperature in intense red auroras of type A, indicates that in this case there is probably a considerable heating of the atmosphere at heights exceeding 200 km. The increase in temperature in these cases could be the consequence of an increase in the mean height of luminescence with an increase in its intensity. However, this explanation seems improbable. In such a case, for example, for an increase in temperature from 1000 to 3000°K at a temperature gradient of 5°/km, there would have to be an increase in the mean height of luminescence by approximately 400 km. ("Interferometric Temperature Measurements of the Upper Atmosphere based on the Width of Certain Emission Lines", by T. M. Mulyarchik, Izvestiya Akademii Nauk SSSR, Seriya Geofizicheskaya, No. 3, 1960, pp. 449-458)

Investigation of Irregular Currents in Ion Counters

A recent article by N. N. Komarov of the Institute of Applied Geophysics of the Academy of Sciences of the USSR deals with irregular currents in the aspiration capacitors of ion counters. The apparatus and methods used are treated in great detail. ("Some Results of the Investigation of Irregular Currents in Ion Counters", by N. N. Komarov, Izvestiya Akademii Nauk SSSR, Seriya Geofizicheskaya, No. 3, 1960, pp. 459-466)

II. OCEANOGRAPHY

Calculation of the Depth of the Layer of Wind Mixing in the Ocean

This article is limited to an analysis of the case of stable density stratification in the upper layer of the ocean (absence of stationary convection). The data used emanates from the American expedition NORPAC which was at work in the northwestern part of the Pacific Ocean in August 1955.

The author, S. A. Kitaygorodskiy, proposes a method for the analysis of the data of oceanographic observations which makes it possible to explain which principal factors determine the mean thickness of the layer of wind mixing in the ocean. As the result of the direct application of this method one can get the necessary formulas for the computation of H . It thereby becomes possible to predict the position of the upper boundary of the jump layer in the ocean.

The text is devoted to the examination of the principal factors determining the depth of wind mixing in the ocean. Formulas are derived relating the thickness of the homogeneous layer with wind velocity, heat flow through the surface of the sea, and the latitude of the place.

The author points out that the study of the roughness regime in the sea differs substantially from the analogous problem in the atmosphere because the roughness parameters are not fixed in the sea but depend on the characteristics of the wind spectrum on the sea surface. Therefore the method of computation of the thickness of the layer of wind mixing seems to merit attention, in his estimation, and is widely applicable for the following reasons, among others:

- 1) The method makes it possible to explain the role of the principal factors (wind, stratification, Coriolis force), determining the regime of turbulent mixing in the friction layer.
- 2) The method is dependent on those empirical data that are presently the most available (H , w , Q , β).
- 3) The direct application of this method also makes it possible to immediately get that result which in practical respects is the most interesting — a concrete form of dependence for the computation of the depth at which the upper boundary of the jump layer is situated.
("On Calculation of the Depth of the Layer of Wind Mixing in the Ocean", by S. A. Kitaygorodskiy, Izvestiya Akademii Nauk SSSR, Seriya Geofizicheskaya, No. 3, 1960, pp. 425-431)

III. SEISMOLOGY

Report by Chinese Seismologist Reflects Increasing Attention to that Science in Communist China

This article is another in a series of presentations on seismic activity and the study of seismology in China; such articles have appeared regularly in recent Soviet technical journals and reflect the activity of Chinese seismologists, the expanding knowledge of seismic conditions in China and the important role played by Russian scientists and institutions in the training and encouragement of Chinese scientists. Seismology, of course, is highly important in China, where geological history has fashioned a highly varied, often unstable and poorly studied surface that is exploited by an exceedingly dense population.

This study of seismic activity in China is based on instrumental observations and historical data reaching back 3,000 years. There are four maps (two fold-out and two page-size) and nine other meaningful figures in the text. Map 1 shows seismic activity in China on the basis of historical data for the period 466 B.C. to 1906 A.D. The epicenters are classified on the basis of earthquake intensity. Map 2 shows seismic activity in China on the basis of instrumental data. The classification of the epicenters is also on the basis of earthquake intensity. Figure 3 is a composite map of the intense earthquakes of China with the epicenters similarly classified. (Six seismic regions are delimited: Tien-Shan, Southwestern, Northwestern, Northern, Southeastern, and Taiwan.) Map 4 shows the seismic activity of China on the basis of a grid with lines drawn for each 5° of latitude and longitude; entered into each such grid square is the value of the logarithm of the total energy of earthquakes in ergs per 50 years and (in brackets) the number of earthquakes with $M \geq 5\frac{1}{2}$ per 50 years.

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The article is broken down into sections: "Source Data"; "Maps of Seismic Activity in China"; "Division of China into Individual Seismic Zones"; "Comparative Analysis of the Seismic Activity of the Different Zones"; "The Recurrence of Earthquakes"; "Change in Seismic Activity in Time"; "Possibility of the Existence of Periodicity in Seismic Activity".

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The author did this study under the direction of Ye. F. Savarenkiy. ("On Seismic Activity in China", by Mei Shi-yung, Izvestiya Akademii Nauk SSSR, Seriya Geofizicheskaya, No. 3, 1960, pp. 381-395)

Izvestiya Akademii Nauk SSSR, Seriya Geofizicheskaya, Presents Second Part of the Study "New Principles of Seismic Regionalization — the Central Tien-Shan as an Example

This is an eighteen-page continuation (Part 2) of an article of the same title appearing in the preceding issue of this journal. The authors continue their treatment of the factors involved in seismic regionalization and present

a series of 7 maps and 1 diagram based on the seismic and geologic data analyzed. The captions to these maps are given below as being highly suggestive of the textual presentation.

Fig. 1. Map of the distribution of the velocity gradient of vertical tectonic movements and the principal elements of the most recent geologic activity of the central part of the Tien-Shan.

Fig. 2. Map of seismic danger in the central part of the Tien-Shan (based on geologic data).

Fig. 3. Map of seismic activity based on data collected by the expedition of the Institute of Physics of the Earth (Academy of Sciences, USSR) during 1957-1958.

Fig. 4. Map of seismic activity based on data of the seismic network of Central Asia, 1950-1956.

Fig. 5. Composite map of seismic activity. Distribution of the mean period of earthquake occurrence.

Fig. 6. Diagram of the estimated seismic danger, based on seismic activity, for calculation of construction norms.

Fig. 7. Map of the detailed seismic regionalization of the central part of the Tien-Shan.

Fig. 8. Map of detailed seismic regionalization of the central part of the Tien-Shan for a short period of time (several hundred years). ("New principles of Seismic Regionalization -- the Central Tien-Shan as an Example", by M. V. Gzovskiy, V. N. Kvestnikov, I. L. Nersesov, and G. I. Reysner, Izvestiya Akademii Nauk SSSR, Seriya Geofizicheskaya, No. 3, 1960, pp. 353-370)

Further Study of Earthquake Prediction

Perhaps the most readily accessible articles in English that are related to this Russian paper by R. M. Karmaleyeva are two articles in the Transactions of the American Geophysical Union (Nishimura and Hosoyama, 34, No. 4, 1953 and Sassa and Nishimura, 32, No. 1, 1951). These studies, by Japanese authors, are among the 7-item bibliography accompanying this article.

The method used in the past and discussed here by the author, is the tilt-meter method which records the tilting motion of the ground observed before and after the occurrence of an earthquake. Sometimes (before nearby destructive earthquakes) the tilt will assume a predominant direction (in the

direction of the epicenter or in an opposite direction) by a few hours or even by several days before an earthquake. Sassa and Nishimura, for example, have pointed out a case where a pronounced tilt in the direction of the epicenter began 10 days before the earthquake.

The author undertook her study of the phenomena forerunning earthquakes in the summer of 1958 on the basis of data accumulated at the seismic station "Stalinabad". She investigated a total of 50 nearby earthquakes ($d < 100$ km); of these 28 were preceded by tell-tale changes in tilt. For nearly 70% of all nearby earthquakes this change occurred 3 to 4 days before the earthquake, for 7% — 2 days, and for 23% — 5 to 7 days. In the case of the strong Stalinabad quake (not included in the preceding 50 cases) the tilting motion foreran the earthquake by 13 days.

In the future it is proposed to study the relationship between the intensity of a nearby earthquake and the character of the tilting motion preceding it.

The author's textual description and analysis of her data is supplemented by 4 tables and 8 graphs.

("Attempt at Prediction of Nearby Earthquakes in Time", by R. M. Karmaleyeva, Izvestiya Akademii Nauk SSSR, Seriya Geofizicheskaya, No. 3, 1960, pp. 467-474)

A Method for Determination of the Refracting Boundary

The method of wave correlation is widely used in seismic reconnaissance and exploration for determination of the parameters of a layered medium. In such cases the seismographs are alined along the profile at some distance from one another.

The same phase of the wave, recorded by the different instruments, can be followed on the seismograms.

G. A. Gamburtsev and his associates in their book "Correlation Method of Refracted Waves" (Publishing House of the Academy of Sciences of the USSR, Moscow, 1952) proposed another form of wave correlation in which the waves are recorded by the use of an azimuthal apparatus. This apparatus consists of several instruments situated at a single point; this apparatus makes it possible to determine the direction of displacement of the soil and, for the longitudinal wave, the direction of the ray arriving at the station. These apparatuses are used both in exploratory geophysics and in seismology — for the recording of local earthquakes.

This article examines the method of determination of the location of refracting surfaces of discontinuity on the basis of recorded data for local earthquakes registered by azimuthal stations. A statistical method is proposed for the determination of the parameters of the refracting surface of the discontinuity. The proposed method makes it possible to use the data of

the azimuthal station to determine the inclination of the refracting boundary and the ratio of the velocities of the longitudinal waves in the upper and lower media.

This method is described in considerable detail and examples are given. The examples examined indicate that the proposed method, even with the use of statistics, permits a quantitative determination of the parameters of the refracting boundary, directly from the directions of the rays recorded by the station. The method requires the recording by azimuthal stations of a large number of different earthquakes, and in such a case insures high reliability of the derived results.

("On Determination of the Refracting Boundary on the Basis of Azimuthal Station Data", by Ye. V. Glivenko, Izvestiya Akademii Nauk SSSR, Seriya Geofizicheskaya, No. 5, 1960, pp. 475-481)

Technical Report on Innovation for Soviet Seismic Stations

The following is the full text of an article written by an associate of the Institute of Physics of the Earth of the Academy of Sciences of the USSR

1. The "Instructions" ("Instructions on the Order of Accomplishment and Processing of Observations at Seismic Stations in the USSR", Moscow, 1958) requires that the pendulum of the SVK seismograph not deviate from its position of equilibrium by more than two graduations on its scale.

Meanwhile one usually observes a gradual lowering of the SVK seismograph pendulum and approximately once each week it is necessary to adjust its position of equilibrium.

We have developed a simple attachment involving the use of a photoresistance (Figure 1) to signal a change in the status of pendulum equilibrium in the SVK seismograph.

The transducer consists of a FSK-1 photoresistance and a special illuminator. The illuminator is a brass tube 18 mm in diameter and 64 mm long. There is a header in one end of the tube with a square-shaped opening (3 mm on each side). A lamp bulb (6.3 volts, 0.28 amps) may be screwed into the socket in the other end of the tube.

The photoresistance and illuminator are situated on the seismograph magnet so that the aperture of the illuminator are situated opposite the light-sensitive layer of the photoresistance. The distance from the illuminator to the photoresistance is 2-3 mm.

Attached to the pendulum coil is a light-weight aluminum plate 4 mm wide. When the "hand" of the pendulum indicator coincides with the zero graduation on the scale, the aperture of the photoresistance is covered with the plate.

When the pendulum moves upward or downward by 1-1.5 graduations the plate uncovers part of the light-sensitive layer, the current in the circuit of the photoresistance F increases and activates the relay P_1 (Figure 1). The contacts of this relay close the circuit of the lamps L_1 and L_2 , one of which is situated alongside the seismograph, while the other is situated in the service quarters of the station. The polarized relay P_1 is unidirectional in operation and after the pendulum has been brought into a position of equilibrium the lamps L_1 and L_2 go out.

The reliable operation of the circuit is insured by the use of a polarized relay RP-4 (the resistance of the operating coil is 2,250 ohms, the diameter of the wire is 0.06 mm, 5,000 turns).

A GB-300 (B_1) battery supplies electricity to the circuit. This battery should suffice for half a year of continual work with a dark current of 20μ a and a capacity of 0.1 amp-hours.

There is a photoresistance with an illuminator and one of the signal lamps in the station cellar. The relay and the second signal lamp are mounted on a common APZO panel. The signal function is accomplished by the burning out of the illuminator lamp.

The described device has been operating at the Central Seismic Station "Alma Ata" since November 1958.

2. We determined the inertia of the FSK-1 photoresistance in relation to the filament voltage of the illuminator lamp of the above-described transducer. Measurements have shown that when the voltage of the illuminator lamp is 6 volts (lamp 6.3 volts, current 0.28 amps) the time for establishment of a current of 100μ at a voltage of 200 volts is about 0.01 second in the FSK-1 photoresistance. The time required for activation of the polarized relay is approximately 0.005 seconds; for the RKN relay — approximately 0.02 seconds.

Thus the time for activation of the entire apparatus in a case where an RKN-type multicontact relay is used is a total of 0.03 to 0.04 seconds.

In this connection, an apparatus similar to that described above is being used at the seismic station "Alma Ata" for the automatic activation of SMR-II seismographs and for the optical recording of SGK seismograms in the course of intense earthquakes (Figure 2).

The aluminum plate, covering the light-sensitive layer of the photoresistance in a clam position, is fastened on the end of the SMR-II seismograph pendulum near the pen. When the plate moves the current increases in the circuit of the photoresistance F, activates the polarized relay P_1 , and then the relay P_2 (type RKN), which activates the starter of the recording apparatus.

The activation of the transducer occurs with the movement of the writing end of the pen a distance of 1.6-2.0 mm. The magnification of the SMR-II instrument is 7; this corresponds to a true displacement of the coil of 200-300 μ .

Figure 3 shows a copy of a part of a seismogram with the recording of the earthquake of 21 December 1958 recorded by a SMR-II seismograph at the station "Alma Ata". At a distance of Δ 300 km this earthquake was felt in Alma Ata with an intensity of 4-5.

The arrow in Figure 3 indicates the moment of the activation of the starter with the photoresistance. Together with the device for 0.5 minute starting of the recording apparatus of the SMR-II and the optical recording during each earthquake (simultaneously with a step-up of incandescence) the described circuit makes it possible to record SMR-II seismograms during the course of the entire earthquake in the case of perceptible shocks.

The proposed transducer may be used in other apparatus where there is need for the signaling of mechanical movements having a value of 1 to 2 mm and more.

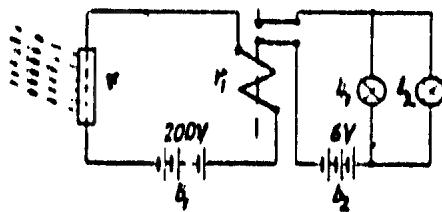


Fig 1

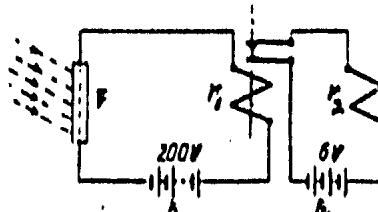


Fig 2

Fig 1. Basic diagram of the signalling device for showing changes in the state of balance of the SVK seismograph pendulum.

Fig 2. Basic diagram of apparatus for switching in SMR-II seismograph recorders and optical recording during strong earthquakes.

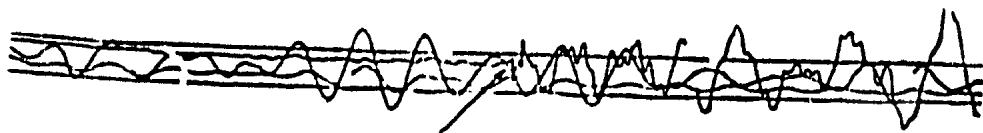


Fig 3. Copy of portions of seismograms with a recording of the 21 December 1958 earthquake (natural value). Station "Alma-Ata", $\Delta = 300$ km, seismograph SMR-II, N-S components.

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"Transducer with Photoresistance for Seismic Stations", by V. M. Fremd, Izvestiya Akademii Nauk SSSR, Seriya Geofizicheskaya, No. 5, 1960 pp. 482-483)

IV. ARCTIC AND ANTARCTIC

Seismology and Gravimetry Yield Data on the Structure of Eastern Antarctica

During the course of the Second and Third Complex Antarctic Expeditions (KAE) geophysical work was conducted in accordance with the Program of the International Geophysical Year; the objective was a clarification of the structure of the Antarctic continent. The work consisted of a complex of seismic and gravimetric observations made at individual points along the profile Mirnyy-Komsomol'skaya-Pole of Inaccessibility, at the station "Vostok" and in a number of coastal regions. (These data were collected and processed by the author, the engineers S. S. Lopatin, S. A. Manilov, and V. I. Koptev, and the technicians A. I. Budnikov and G. Ye. Vorog'yev.) The total length of the main profile was 2,100 km. Seismic observations were made at 70 points along this profile, while gravimetric observations were made at 84 points. (This article only provides data and the results for gravimetric work accomplished by the Third Complex Antarctic Expedition. The results of the gravimetric work of the Second Complex Antarctic Expedition are in part presented in the Doklady of the Academy of Sciences of the USSR, 126, No. 2, 1959.) The coastal regions were studied in the greatest detail. The density of the seismic observation points in the first 60 km of the profile was 1-3 km, in the sector between km 60 and km 375, the points were 10-25 km from one another, while in the sector between km 375 and km 2,100 — 50 to 150 km apart. Gravimetric observations in the central regions were made each 25-30 km.

The following were determined by means of seismic reconnaissance: the depth at which bedrock is situated, the thickness of the upper snow-firn cover, and data on the velocity of wave propagation in the glacier and underlying rocks. Under Antarctic conditions the seismic method is the only quantitative method usable for determination of glacier thickness. The gravimetric method, technically easier to use than the seismic method, makes it possible to determine in detail the thickness of the glacier at points between the seismic research control points. Gravimetric data also provided information concerning the deep geological structure of individual areas and of the region as a whole. The data supplied by these two geophysical methods complement one another and this dictates the necessity of their joint utilization.

The method of seismic research. The determination of the thickness of the glacier was accomplished for the most part by the method of reflected waves in its high-frequency modification. Work by the correlation method of refracted waves was accomplished on a lesser scale and in most cases for the clarification of the nature of the recorded waves and determination of their velocity of propagation.

The reception of reflections from the boundary between the ice and the bedrock in the coastal region (up to 150 km from the coast) presented no

difficulties. Here these waves were clearly readable on the seismograms and the background of interference was small. On proceeding into the interior of the continent the wave picture changed. The relative intensity of the surface waves, propagated in the upper parts of the cross section, increased. Simultaneously on the seismograms there were recorded irregular variations of the background of interference; this made it difficult to read the reflected waves. In the central region (more than 250 km from the coast) the background of interference became so intense that the recording of usable reflected waves proved to be impossible when using ordinary procedures.

Special research has shown that the indicated change in the wave picture in the central regions of Antarctica is associated with the structure of the upper part of the snow-firn stratum. This stratum is characterized by a nonhomogeneous structure and the presence in the upper part of the cross section of wave-conducting layers characterized by reduced velocities. The nonhomogeneity of the stratum increases with distance from the coast and there is a simultaneous decrease in the damping and velocity of propagation of elastic waves in the upper wave-conducting layer (from 1,500 m/sec in the coastal regions to 600 m/sec at the Pole of Inaccessibility). The cited conditions cause a considerable increase in the background of interference in the central regions of Antarctica.

In addition, the nonhomogeneous layers of the snow-firn stratum play the role of high-frequency mechanical filters, attenuating the amplitude of the reflected waves in the entire range of seismic frequencies and enriching the spectrum of these waves with high-frequency components.

As a result of the simultaneous action of the mentioned factors in the central regions of Antarctica, the ratio of the amplitude of the reflected waves to the amplitude of the background of interference sharply decreases in comparison with this ratio in the coastal regions.

As a result, during the Second Complex Antarctic Expedition reliable data on the thickness of the glacial cover were only derived to km 250 of the profile; farther to the south, to the vicinity of the station "Pionerskaya", approximations were made of the depth at which the bedrock was situated. However, by this time the principle causes of the absence of reflections were understood and recommendations were made for refinement of the method. The seismic team of the Third Complex Antarctic Expedition, by drilling deep explosive holes to km 60 and increasing the resonant frequency of the filtering apparatus to 150 cycles, was able to read the reflected waves and derive reliable data in the central regions. The possibility of using high-frequency filtration during reconnaissance of depths of several kilometers is based on the relatively small absorption of seismic energy in the ice stratum and the specific structure of the upper nonhomogeneous snow-firn mantle. As a rule, in the central regions of Antarctica the reflected waves were recorded with an apparent frequency on the order of 150-200 cycles.

The accuracy of determination of the thickness of the ice cover (when the nature of the waves is correctly interpreted) for the most part depends on the accuracy of determination of the velocity of propagation of the waves in the medium. The mean (effective) velocity was computed on the basis of data derived in the course of continuous observations along several longitudinal profiles in the coastal zone (to km 150) and at "Komsomol' skaya", where reflected waves were clearly readable on the seismic recordings. The mean velocity in these regions is $3,750 \pm 70$ m/sec. Velocity on such an order was assumed during the interpretation of data in both coastal and central regions. In this case we may assume that the accuracy of determination of depths by the seismic method is $\pm (2-5\%)$.

Data on the velocities in the underlying rocks (boundary velocities) were collected up to km 50 from the coast. The value for this velocity, 5,500 to 5,800 m/sec, is evidence that under the ice there are crystalline rocks similar to those situated in the vicinity of Mirnyy. In addition, data were collected about the velocity structure and thickness of the upper snow-firn cover. The depth at which the firn-ice seismic boundary is situated gradually increases from zero near the coast to 170 m at the Pole of Inaccessibility.

The results of determination of the thickness of the ice cover were used for the drawing of the composite cross section (Figure 1), which will be described below.

It should be noted that in an article by G. Ye. Lezarev and S. A. Ushakov (Doklady AN SSSR, 126, No. 2, 1959) their correct conclusion in respect to the need for joint utilization of seismic and gravimetric methods in the study of Antarctica was based on wrong reasoning in respect to the low accuracy of seismic reconnaissance. The statement in that article that there was a 600-meter discrepancy in the position of the basement rock between the data collected by the seismic method during the Second and Third Complex Antarctic Expeditions is erroneous. The authors did not take into consideration that the seismic groups of the Second and Third Antarctic Expeditions did not accomplish their work at the same points and that for some regions (the station "Pionerskaya") the seismic data of the Second Complex Antarctic Expedition were used only for making approximate estimates of the probable thickness of the ice sheet. This same article provided an incorrect explanation for the increasingly poorer quality of the reflected waves in the central regions; they attributed this to an increase in the thickness of the snow-firn cover, which in itself plays a subordinate role (see above).

Method of gravimetric research. The gravimetric observations of the Third Complex Antarctic Expedition were made simultaneously with three SN-3 gravimeters with a thermostat setting of 0° ; this insured minimum displacement of the null-point. All observations, with the exception of the

stretch between the stations "Sovetskaya" and "Pole of Inaccessibility", were connected by a closed net of aircraft determinations based on the main stations of the profile. The observational error along the main profile does not exceed ± 1.0 mgl, except for a few points where it is ± 2.0 mgl.

The interpretation of gravimetric data for the purpose of computing depths at intermediate points between the seismic reference points was made in the following manner. The normal field was reckoned by use of the Helmert formula (1908), while the regional background was determined from the Bouguer anomalies computed at the points of joint seismic and gravimetric observations; the observations assumed that the mean density of the ice is 0.9 g/cm^3 , and that of the underlying rock is 2.67 g/cm^3 . After averaging of the regional background the thickness of the ice at intermediate points was computed from the difference between the Faye anomaly and the regional background by use of the formula for an infinitely plane-parallel stratum.

When using seismic data the accuracy of calculation of the regional background is approximately ± 10 mgl. The mean square error of the determined elevations, made by V. A. Bugayev by the method of aircraft barometric levelling, is ± 20 m; this leads to an error of ± 6 mgl on conversion to the Faye anomaly. With a total mean square error of ± 12 mgl, the accuracy of determination of the depth at which bedrock is situated, relative to the determinations made at seismic reference points (and assumed to be true) is ± 160 m.

The accuracy of interpretation of gravimetric data depends considerably on the proper calculation of the regional background; in the case at hand this can be determined only by the use of seismic determinations. The processing of gravimetric data alone leads to a considerable distortion of the cross section. In figure 1, for comparison, the position of the ice-bedrock boundary is given; this was derived by the interpretation of gravimetric data alone. In the coastal regions this cross section to some degree reflects the actual structure of the glacier. Farther inland, however, the error in depth determination increases and in the region of the central mountain structures it attains 2.0-2.5 km, or 300-350%; this is associated for the most part with an increase in the thickness of the Earth's crust in this same direction (see below), leading to substantial additional distortions of the gravitational field.

This comparison also points to the erroneousness of some basic systematic conclusions made in the previously cited article. G. Ye Lazarev and S. A. Ushakov use the example of a small 25-kilometer profile, situated in the coastal region, where the thickness of the Earth's crust remains practically constant, to indicate that under Antarctic conditions gravimetric determinations of the thickness of the ice that are "tied" to depth at only one point, give results that are no less precise than seismic

determinations (and judging by the examples, even more precise). It has been indicated above, however, that it is generally impossible to make an interpretation of gravitational anomalies over long sectors of a profile without the use of seismic data.

The second erroneous contention in this article is the conclusion: "If there is isostatic compensation of the ice cover over a considerable area of Eastern Antarctica, the regional background can be represented by a curve of the gravitational effect of the ice situated at elevations above sea level, with an opposite sign (by the graph of Bouguer corrections) with the density of ice 0.9".

Since the regional background is determined by Bouguer corrections, this conclusion already assumes in advance that the bed of the glacier should everywhere be situated below sea level. But in actuality in the overwhelming part of the profile the bed of the glacier is situated above sea level (see below for more details). Therefore the proposed method of interpretation cannot be successful and the conclusion about the correspondence of the regional background to the gravitational effect of the ice for a large part of Antarctica is erroneous; this is clearly demonstrated by a comparison of the graph of Bouguer anomalies with the drawn cross section of the ice cover.

Structure of Eastern Antarctica on the basis of seismic and gravimetric data. On the basis of the composite cross section (Figure 1) and gravitational anomalies, it is possible to draw the following basic conclusions about the structure of the central sector of Eastern Antarctica. (It must be borne in mind that the depths were only determined at individual points; the cross section in Figure 1 is therefore only schematic. Until recently there was much discussion in the literature as to whether Antarctica is a continent. The solution of this problem depended on the results of determination as to the depth at which the bedrock is situated. At the same time, independently of the level at which the glacier bed is situated, we may conclude on the basis of certain geological and oceanographic data on the structure of the coastal parts of Eastern Antarctica that this is a typical continent, and not a gigantic archipelago buried beneath the ice). In approximately the first 200 km from shore the bed of the glacier is situated near sea level. Individual swells and swales may be noted here. Beginning at km 200 the bedrock rises sharply and forms a plateau-like highland traceable approximately to km 400 and characterized by a mean elevation of 600 to 700 m above sea level. Farther to the south there is a deep canyon-like depression with minimum elevations of -1,130 meters. At this point the glacier is 4,060 m thick, the maximum for the entire profile. In the sector km 550 to km 1,000 the subglacial bed has relatively small positive elevations. Beyond the station "Komsomol'skaya" the bedrocks rise again, forming a major mountain massif whose highest point

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is 3,000 m above sea level (in the vicinity of km 1,700 of the profile). In this sector are also to be found the highest elevations of the glacier surface, rising to as much as 4,000 m. Farther to the south the subglacial bed drops off and has elevations of > 800 m in the vicinity of the Pole of Inaccessibility.

The bedrock is situated above sea level in sectors with a total length of 1,800 m (approximately 85% of the length of the profile). The mean elevation of the glacier bed is 800 m above sea level, while the mean thickness of the ice cover is 2,200 m. Inasmuch as Eastern Antarctica has approximately a symmetrical structure, while the profile in question extends from the coast to the central part of the continent, the figures that have been cited evidently reflect the order of values for the entire continent.

Guided by the seismic data for depth determination, it is possible to make an interpretation of the gravitational field and draw some geological conclusions. The anomalies, computed in the Faye and Bouguer reductions, have an obviously continental character. The Faye anomalies are insignificant and locally are associated with the buried relief of the bedrock. For that sector of the profile to km 500, the character of the anomalies gives evidence of the occurrence here of deep structures of the horst and graben types. This confirms the conclusions that geologists have already made about the structure of Eastern Antarctica in the coastal zone.

The character of the Faye anomalies indicates that Antarctica is in equilibrium. The continent has settled by approximately 750 m under its colossal load of ice.

The Bouguer anomaly is negative, has a regional character, and in absolute value increases in a direction toward the center of the continent. Simultaneously in this same direction there is an increase in the level at which the bedrock is situated. This latter circumstance is evidence of an increase in the thickness of the Earth's crust in the central regions. Thus, the clearly expressed deep roots of the mountains clearly correspond to the central mountain massif. Approximate computations indicate that the thickness of the crust is 18 km here than it is in the vicinity of Mirnyy.

It is highly probable that the buried mountain structures discovered in the central regions are platform formations that have been subjected to preglacial erosion. Evidently the central uplift is the main structural element with which smaller peripheral structures are associated. Evidence of this is certain geological data and the character of the relief of the surface of the ice cupola.

Taking into account data concerning isostatic compensation, we may assume that before glaciation Eastern Antarctica was one of the highest continents (mean elevation up to 1,500 m). The existence of a high continent in the region around the pole also probably caused the formation of the colossal glaciation which is not present in Antarctica.

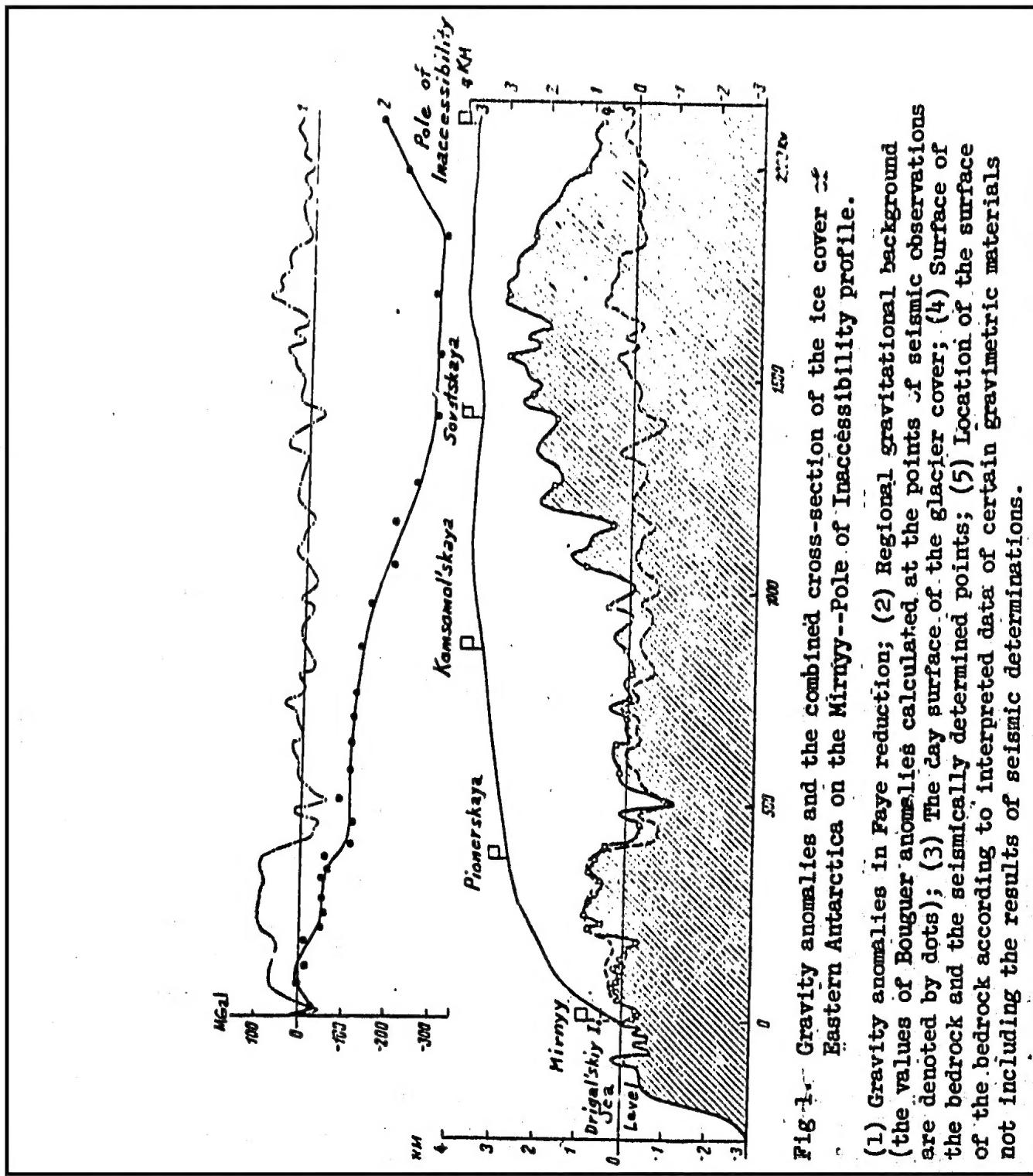


Fig. 1. Gravity anomalies and the combined cross-section of the ice cover in Eastern Antarctica on the Mirnyy--Pole of Inaccessibility profile.

(1) Gravity anomalies in Faye reduction; (2) Regional gravitational background (the values of Bouguer anomalies calculated at the points of seismic observations are denoted by dots); (3) The day surface of the glacier cover; (4) Surface of the bedrock and the seismically determined points; (5) Location of the surface of the bedrock according to interpreted data of certain gravimetric materials not including the results of seismic determinations.

("Method and Basic Results of Seismic and Gravimetric Research on the Structure of Eastern Antarctica", by O. G. Sorokhtin, O. K. Kondrat'yev, and Yu. N. Avsyuk, Izvestiya Akademii Nauk SSSR, Seriya Geofizicheskaya, No. 3, 1960, pp. 396-401) ✓

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